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ESTIMATION OF ABSOLUTE HUMIDITY DURING MORNING FOG IN CENTRAL E--ETC(U)
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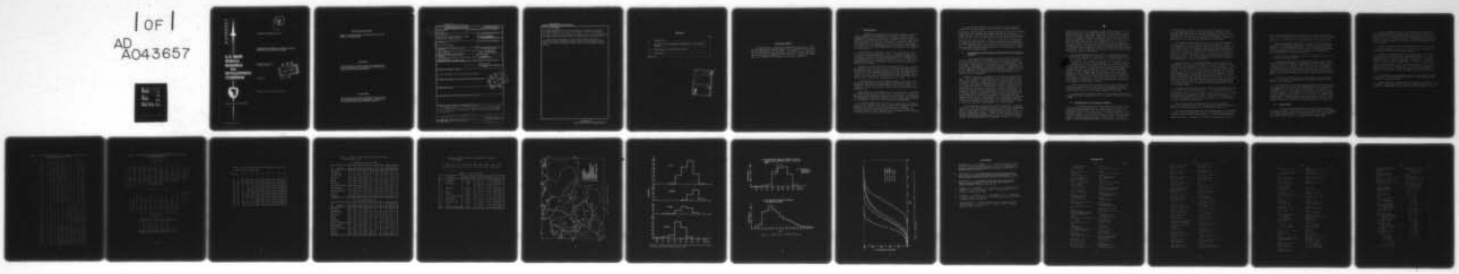

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ESTIMATION OF ABSOLUTE HUMIDITY DURING MORNING FOG IN CENTRAL EUROPE

U.S. ARMY
MISSILE
RESEARCH
AND
DEVELOPMENT
COMMAND

Physical Sciences Directorate
~~Technology Laboratory~~

Redstone Arsenal, Alabama 35809

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A tentative estimate of the distribution of the absolute humidity during fog in Central Europe is given via the frequency distribution of the temperature, assuming 100% relative humidity. Only the morning hours were examined for 10 stations.

It was learned that 7.5 g/m^3 is exceeded in only one-third of the cases, of which 80% occur in summer and fall. An absolute humidity higher than

ABSTRACT (Continued)

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9.4 g/m^3 is encountered in 7% of the fog cases in spring and 18% in fall. Fall contributed 45% to the annual fog occurrence. While the threshold of 9.4 g/m^3 is exceeded in two-thirds of the summer cases, the total contribution from summer fogs to the entire number of fogs during the year is only 15%.

The frequency distribution of the absolute humidity during fog is exhibited and can be converted to visual range for electro-optical systems when the functional relationship absolute humidity-electro-optical system is known.

CONTENTS

		Page
I.	INTRODUCTION.	3
II.	ESTIMATION OF THE FREQUENCY DISTRIBUTION OF THE ABSOLUTE HUMIDITY.	4
III.	DISTRIBUTION OF THE ABSOLUTE HUMIDITY	5
IV.	CONCLUSIONS	7
REFERENCES		18

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I. INTRODUCTION

Climatological information on standard atmospheric elements such as temperature or precipitation is abundant. Other moisture characteristics such as visibility or clouds are available largely for airports or in unpublished tabulations. Frequency distributions of the absolute humidity are virtually non-existent. The primary concern of this report is the distribution of the absolute humidity during fog. This survey is a quick approximation of the atmospheric water vapor content during fog in Central Europe based on estimation via the temperature distribution.

Two points may be stressed. First, in the available time for this survey it was not possible to furnish a complete distribution of the absolute humidity during fog because the absolute humidity is not an ordinary element to be observed and reported in the synoptic code. The estimation which is described in detail in Section II serves as a simplification for the calculations, and is sufficient for practical purposes at the moment.

Second, it is well known among meteorologists that fog is defined as visibility below or equal to 1 km. It is also well understood in atmospheric science that fog has a distinct diurnal and seasonal variation as well as an orographic dependence, e.g. see Essenwanger and Stewart [1, 2, 3]. Thus, fog probabilities without the proper specification of all three stratification factors are of limited value, e.g. Moulton et al., Table I [4], Biberman et al., p. 2 [5].

In the present survey of the absolute humidity the morning hour for fog has been chosen for 10 stations during the four seasons. The limitations imposed by the selected data are examined in detail in Section II. It can be concluded, however, that the results are fairly representative.

Nonetheless, the conclusions from this survey should be considered as tentative, and the actual numbers may change slightly if a detailed and true frequency distribution of the absolute humidity is established. The results are commensurate, however, with the commonly known behavior of the atmosphere, and they do not surprise the meteorologist.

It should be noted first that 45% of the fog cases in the morning hours in Central Europe occur during the fall season [September through November, see Table 2]. This fact is frequently overlooked. The result is not a conclusion from a single station but is based on a 10-station network, although probably every individual author would pick a different set of stations (see Section II).

The low absolute humidity for the majority of the fog cases may surprise the non-meteorologist. From the yearly summary of the 10 stations in Central Europe, the absolute humidity of 7.5 g/m^3 is exceeded roughly only in one-third of the cases, about 80% thereof occur in summer and fall. As disclosed in Table 2(b) only 7% of the fog cases in spring and 18% in fall are associated with an absolute humidity higher than 9.4 g/m^3, none in winter. Although this threshold is exceeded in two-thirds of the summer fogs it must be considered that morning fogs in summer contribute only a total of 15% to the fog cases of the entire year. In addition, the duration of morning fog is considerably reduced in summer (see Essenwanger and Stewart [1]). A discussion of the specific tables and graphs follows.

II. ESTIMATION OF THE FREQUENCY DISTRIBUTION OF THE ABSOLUTE HUMIDITY

It was previously mentioned that frequency distributions of the water vapor content of the atmosphere are not readily available. The absolute humidity is not one of the ordinary elements which is regularly observed and reported in the synoptic code like temperature and visibility. Consequently, the absolute humidity must be specially calculated before its distribution can be established. Although this computation imposes no technical difficulty, the establishment of a computer program for the calculation of this moisture parameter is not simple and is time consuming.

The major interest at the moment is the moisture content during fog. It is a reasonable assumption that the relative humidity during fog is close to 100%. In fact, theoretically it should be 100%, but in practical work fog is encountered with a relative humidity of less than 100%. Consequently, approximating the absolute humidity in fog by the absolute humidity at saturation will yield an amount slightly higher than the true value in some cases. However, the effect on the statistical characteristics is expected to be nearly negligible. It simplifies the task for the establishment of a frequency distribution of absolute humidity considerably, however, because this problem can now be reduced to the producing of frequency distribution for the temperatures during fog. The temperature can be converted to absolute humidity by one simple transformation, e.g., as provided in Table 5 for the class boundaries of this study. The converted value is added in Table 2 (b) and can be simply applied to the other tables.

A second problem is the selection of fog conditions. As pointed out earlier, the time and space variabilities of fog make it extremely difficult to provide a reliable estimate derived from one station. The author is well aware that the 10 selected stations may not lead to a precise climatological average. Indeed, Schulze-Neuhoff [6] has only recently delineated the deficiencies inherent in a limited network of stations and has demonstrated the orographic variability in a single

weather situation by the utilization of 420 climate stations for the proper analysis of an area comprising largely Western Germany. The 10 selected stations for this report (see Table 6 and Figure 1) display a variety of mesoscale conditions. Therefore, the only question remains whether the summary of these 10 stations provides a proper mixture, or gives disproportionate weights to extreme conditions. A careful examination of the climatic regime under consideration reveals, however, that the derived estimate from the 10 stations is fairly representative. An added cluster of stations from one side of extreme fog conditions, e.g. too high (see Grafenwöhr or Fulda), or too low (see Berlin), appears unwarranted. However, additions of stations close to the average would virtually not alter the frequencies.

This leaves undecided the time of the day, because the seasonal fluctuations are included into this report. A closer perusal of the diurnal variation renders the result that the maximum frequency of fog shifts from 06^h AM GMT in summer time to 09^h AM (GMT) in winter time parallel with the cycle of sunrise (see Table 4). In order to provide a uniform time for the total year the morning hour of 06 was finally chosen, where frequency of occurrence is not far behind in winter time. One may argue that this may generate a bias towards lower absolute humidities than the one obtained from noon data. This is factually correct. It must be added, however, that fog at noon is virtually non-existent during summer time, where the higher absolute humidity would count. Thus, the bias which lowers the influence of high absolute humidity is negligible or may be non-existent, and is within the error range of the estimation. It is also compensated in some way by the assumption of 100% relative humidity.

It must be further taken into account that on days where fog continues from the morning hours into the day the increase in absolute humidity is low due to the closeness of the atmosphere to saturation conditions and the low influx of solar radiation for warming.

In conclusion, the estimates given in the subsequent tables may be considered as fairly representative of the climatic conditions in Central Europe.

III. DISTRIBUTION OF THE ABSOLUTE HUMIDITY

It is obvious from Table 6 that the period of record for the 10 stations was not homogeneous, and some distortion in the frequency distribution would result from this varying length of record. The tabulation could have been restricted to the period 1960-1970. It was desirable, however, to include the data for the total available period of record largely because of the low frequency of fog during spring and summer. This longer period provides a better balance. In order to make the material homogeneous, however, the data were standardized to

a 10-year period of record. Thus, the value N = 63.9 of Table 5 for STU = Stuttgart means that for the winter season (December through February) for 900 days during a 10-year period fog occurred on a standardized number of 63.9 days. This figure corresponds to a fog frequency of 7.1% in a single winter season in the average. Similar interpretations must be given for the other stations and seasons.

The frequency distribution from Table 1 can then be interpreted as 38.1 days of the 63.9 days falling into the class from 20° to 32°F. The threshold 32 was chosen because later in the cumulative summary the "cold fogs" as defined by fogs with temperatures below 32 degrees can be quickly obtained. The expansion of this particular class and the reduction of the adjacent class from 32° to 40°F does not introduce a bias into the cumulative distribution. The effect is only an unequal spacing of classes. Because equal spacing in temperature means a nonlinear progression of the class boundaries for the absolute humidity this modification is without significance.

The distribution of the absolute humidity in fog at 06 AM (GMT) is disclosed in Table 2 (a) and Figures 2 and 3 for the season and the total year. These summaries are based on the data of Table 5. As shown in these data, the mode for the year occurs in the class between 40° and 50°F. It must be called to the attention, however, that the class interval from 32° to 40° is shorter than the other intervals. Taking under consideration the values from 30° to 32° and adding them to this short interval class, the true peak shifts into the 30° to 40° class interval [see Figure 3(a) and adjusted row in Table 2(a)]. In the yearly summary the unequal class division introduces a noticeable distortion in the frequency distribution. While the actual numbers would change in the other seasons, too, the mode is not shifted to another class in the individual season.

The next to last row of Table 2(a) delineates the conversion of the yearly summary to a percentage frequency. It is obvious that values of an absolute humidity of 9.4 g/m^3 occur in less than 20% of the fog cases. This adds up to an average of 63 cases in 10 years per station. A maximum of 113 is disclosed for Fulda. In terms of the individual year this can be interpreted as 6.3 or 11.3 days per year for the average or maximum (station), respectively.

The frequency density distribution for the annual summary is exhibited in Figure 3(a) which has been converted to equal class intervals of the absolute humidity and is displayed in Figure 3(b).

The cumulative percentages for the individual seasons are exhibited in Table 2(b) and illustrated in Figure 4. As expected, the annual percentage curve lies between spring and fall, and the extreme bounds are summer and winter. Although 36% of the total cases exceed 7.5 g/m^3 it

should also be noted that most of these occur in summer and fall [see Table 2(c)]. This amounts to 12 cases per year with an absolute humidity higher than 7.5 g/m^3, with 4 in the summer season and 7 during fall.

The non-meteorologist accustomed to assuming 7.5 g/m^3 as an average value may be somewhat surprised by the lower values of the absolute humidity. It may be explained, however, that higher values would be obtained by the inclusion of all non-fog cases. Furthermore, afternoon values would be higher, too, but the fog frequency is considerably reduced, especially in summer (see Table 4).

Finally, Table 3 provides the cumulative distribution for the total year at each individual station.

As previously mentioned, an added benefit of the frequency distribution of the absolute humidity by temperature classes is the information on the mumber of cases of "cold" and "warm" fog. As exhibited in Table 2(b), in the average 64% of the fog cases in winter appear to be cold fogs, and 26% of the total fog cases per year. Table 6 displays this split of fog cases for the year at the individual stations. Here 32°F was assumed as the dividing line although some authors select 30°F.

It should be reiterated that the given survey is a first approximation. More details, and especially the diurnal variation will be provided at a later data.

The meteorological definition of fog comprises all data with visibility less than or equal to 1 km irrespective of the cause of obscuration except for dust storms which are eliminated. These storms are extremely rare in Central Europe, but low visibility in winter may be caused by snowfall. Since fogs with precipitation differ considerably in their droplet size distribution, it is of interest to separate pure radiation fogs from other types. This problem will be part of a forthcoming report. Some preliminary results have been presented during a special conference in December 1976 (see Essenwanger and Stewart [1]).

IV. CONCLUSIONS

It should be reiterated that the frequency distributions of the absolute humidity during fog in Central Europe should be considered as tentative results although the final frequency counts are not expected to be drastically different. The limitation is largely based on the fact that the distribution is strictly valid for morning fogs.

It has been explained that the actual frequency distribution can only be established after calculations of the absolute humidity content which was too time consuming at the present time. Because the major interest is the distribution of the absolute humidity during fog, a relative humidity of 100% was assumed. This postulation reduces the task to the establishment of a distribution for the temperature, which is very simple.

The major surprise to the non-meteorologist may be the fact that the absolute humidity is higher than 7.5 g/m^3 in only one-third of the fog cases of which 80% occur in summer and fall.

It should be stressed that 45% of the fog cases (for the 10 station network) occurred during fall (September-November). This fact changes some of the concept of many fog studies because the temperatures are higher in fall than in winter. Consequently, the absolute humidity is higher during the fall season. It can be learned, however, that the absolute humidity is higher than 9.4 g/m^3 only in 18% of the cases in fall, and 7% in spring. While the threshold is exceeded in summertime in two-thirds of the cases, summer fog contributes only 15% of the annual total. Generally, summer fogs are of shorter duration.

It is necessary to provide additional information for the diurnal variation of the absolute humidity during fog. This examination will be part of a forthcoming study.

Under consideration of attenuation of electro-optical systems affected by the moisture content of the atmosphere, Figures 3(b) or 4 could be directly transformed into a range scale of electro-optical vision.

TABLE 1. DISTRIBUTION OF TEMPERATURE DURING FOG AT 06^{h} AM (GMT)
(STANDARDIZED 10 YEAR PERIOD)

Season	Station	-10	0	10	20	32	40	50	60	70°F	N	%
Winter	Stu		0.4	3.3	7.8	38.1	13.1	1.2			63.9	7.1
	Hei	2.3	0.6	3.5	8.1	36.9	17.3	1.2			69.9	7.8
	Bit				4.9	43.0	51.1	11.4			110.4	12.3
	Ha			0.6	6.9	82.3	56.4	10.4			156.6	17.4
	Sem			0.6	4.8	35.4	34.2	4.8			79.8	8.9
	Fue		1.8	16.3	27.2	77.0	15.4				137.7	15.3
	Gra		4.8	6.8	3.9	31.8	27.0	1.0			75.3	8.4
	Fra				2.9	33.3	27.1	2.9			66.2	7.4
	Ful		3.4	3.4	9.1	30.6	15.9	1.1			63.5	7.1
	Ber		0.4	2.0	2.5	16.4	21.3	1.2			43.8	4.9
Spring	Stu				2.1	9.2	13.8	10.4	2.5		38.0	4.1
	Hei				0.6	7.9	7.9	6.2	2.3		24.9	2.7
	Bit				1.1	4.4	20.4	17.7	5.5		49.1	5.3
	Ha				0.6	10.1	26.6	27.8	8.9		74.0	8.0
	Sem				0.6	4.3	12.8	9.2	4.3		31.2	3.4
	Fue			1.7	2.6	12.8	18.7	11.9			47.7	5.2
	Gra			1.9	0.0	22.7	44.4	32.1	3.8		104.9	11.4
	Fra				0.4	4.2	9.6	7.5	2.5		24.2	2.6
	Ful			1.1	1.1	15.3	25.2	32.9	5.5		81.1	8.8
	Ber				1.2	3.2	9.7	5.3	0.4		19.8	2.2
Summer	Stu							4.6	15.0	2.9	22.5	2.4
	Hei							2.3	9.1	4.5	15.9	1.7
	Bit							15.8	31.6	4.9	52.3	5.7
	Ha							9.9	45.8	8.1	63.8	6.9
	Sem						0.6	14.6	33.3	4.7	53.2	5.8
	Fue							12.4	19.5	0.9	32.8	3.6
	Gra						8.4	56.0	46.7	0.9	112.0	12.2
	Fra							4.6	14.2	3.8	22.6	2.5
	Ful							41.6	63.5	6.6	111.7	12.1
	Ber								2.0	0.4	2.4	0.3
Fall	Stu				0.8	20.0	39.5	50.9	28.1		139.3	15.3
	Hei					10.0	30.0	57.7	25.3	2.9	125.9	13.8
	Bit					14.8	44.4	56.5	32.3	1.1	149.0	16.4
	Ha					21.9	41.5	77.9	39.8	2.2	183.3	20.1
	Sem					14.6	46.1	56.6	23.9	1.8	143.0	15.7
	Fue				2.6	42.9	54.9	51.5	24.9		176.8	19.4
	Gra				1.9	36.6	74.2	75.1	19.7		207.5	22.8
	Fra					10.0	30.4	50.8	26.0	0.8	118.0	13.0
	Ful				1.1	39.9	62.6	97.9	36.4	1.1	239.0	26.3
	Ber					5.2	16.4	24.8	9.6		56.0	6.2

TABLE 2. DISTRIBUTION OF TEMPERATURE DURING FOG AT 06^{h} AM (GMT)
(10 Station Average)

(a) Number of Cases
(Per 10 Years)

	-10	0	10	20	32	40	50	60	70 F	N	%
WI	0.23	1.14	3.65	7.81	42.48	27.88	3.52			86.71	9.63
SP			0.47	1.03	9.41	18.91	16.10	3.57		49.49	5.38
SU						0.90	16.18	28.07	3.77	48.92	5.31
FA				0.64	21.59	44.00	59.96	26.60	0.99	153.78	16.90
Year	0.23	1.14	4.12	9.48	73.48	91.69	95.76	58.24	4.76	338.90	9.30%
%	0.07	0.34	1.21	2.80	21.68	27.06	28.26	17.18	1.40%		
Adjusted to equal class intervals					(18.05)	30.74					

(b) Cumulative Percentage

	0.8	1.3	2.0	3.0	4.85	6.55	9.4	13.3	g/m^3 18.5	Percentage of Total Year
WI	0.3	1.6	5.8	14.8	63.8	95.9	100.0			25.6
SP			0.9	3.0	22.0	60.2	92.8	100.0		14.6
SU						1.8	34.9	92.8	100.0	14.4
FA				0.4	14.5	43.1	82.1	99.4	100.0	45.4
Year	0.1	0.4	1.6	4.4	26.1	53.2	81.4	98.6	100.0	

(c) Number of Cases Exceeding a Special Threshold
(Per 10 Years)

	Threshold				
	4.85	6.6	7.5	9.4	13.3 g/m^3
WI	31.40	3.52	2.1	0	
SP	38.58	19.67	13.1	3.57	
SU	48.92	48.02	41.6	31.84	3.77
FA	131.55	87.55	65.6	27.59	0.99
Year	250.45	158.76	122.5	63.00	4.76

TABLE 3. CUMULATIVE DISTRIBUTION OF TEMPERATURE DURING FOG AT 06^{h} AM (GMT) (TOTAL YEAR)

Station	-10	0	10	20	32	40	50	60	70°F	
									%	N
Stu		0.2	1.4	5.5	31.0	56.2	81.6	98.9	100	264
Hei	1.0	1.2	2.7	6.4	29.5	52.9	81.4	96.9	100	237
Bit				1.7	18.9	51.0	79.1	98.3	100	361
Ha			0.1	1.7	25.6	51.7	78.1	97.8	100	478
Sem			0.2	2.0	19.6	50.1	77.9	97.9	100	307
Fue		0.5	5.0	13.2	46.8	69.3	88.5	99.7	100	395
Gra		1.0	2.7	3.9	22.1	52.9	85.8	99.8	100	500
Fra				1.4	22.0	51.0	79.5	98.0	100	231
Ful		0.7	1.6	3.9	21.2	42.1	77.2	98.4	100	495
Ber		0.3	2.0	5.0	25.3	64.2	89.8	99.6	100	122

TABLE 4. DIURNAL VARIATION OF FREQUENCY (PERCENTAGE) OF VISIBILITY ≤ 1 km

(a) December through February

Station	00	03	06	09	12	15	18	21 GMT	All (%)
Stuttgart	5.4	7.2	7.9	7.6	3.5	2.8	2.9	3.9	5.1
Heidelberg	7.5	7.9	8.5	11.0	7.8	6.3	6.8	6.2	7.7
Bitburg	9.6	11.4	12.5	13.2	9.1	7.3	7.0	7.9	9.8
Hahn	16.2	18.1	18.1	19.7	15.8	14.6	14.0	13.5	16.2
Sembach	6.7	7.7	8.5	11.3	7.1	5.2	5.6	5.7	7.2
Fuerstenfeldbruck	16.0	16.8	16.3	13.0	7.2	7.2	11.3	14.4	12.8
Grafenwoehr	6.3	6.9	8.6	11.2	5.2	3.0	4.4	5.9	6.5
Frankfurt/Main	6.2	6.8	7.7	9.9	6.5	6.2	4.8	5.3	6.7
Fulda	3.5	3.9	7.5	9.7	6.5	3.6	3.7	2.2	5.9
Berlin	3.5	4.2	4.9	7.2	4.3	2.9	2.4	2.8	4.0

(b) June through August

Station	00	03	06	09	12	15	18	21 GMT	All (%)
Stutgart	0.4	1.7	2.2	0.2	-	-	-	0.0	0.6
Heidelberg	0.2	1.0	1.7	0.2	0.0	0.0	0.0	0.0	0.4
Bitburg	0.8	3.3	5.5	0.5	0.0	0.1	0.0	0.2	1.3
Hahn	2.3	5.6	6.5	1.6	0.5	0.3	0.7	1.0	2.3
Sembach	0.9	3.3	5.3	0.7	-	-	0.0	0.2	1.3
Fuerstenfeldbruck	0.9	3.2	3.4	0.3	-	0.0	0.1	0.1	1.0
Grafenwoehr	1.7	6.0	10.6	1.3	0.0	--	-	0.2	2.4
Frankfurt/Main	0.2	1.5	2.1	0.2	-	0.0	0.0	0.0	0.5
Fulda	1.3	6.8	11.3	2.8	0.1	-	-	-	2.9
Berlin	0.1	0.4	0.4	0.1	0.0	-	0.0	0.0	0.1

TABLE 5. ABSOLUTE HUMIDITY (SATURATION) AS FUNCTION OF TEMPERATURE

T	-10	0	10	20	32	40	50	60	70	°F
H_a	0.82	1.29	1.99	3.02	4.85	6.55	9.40	13.27	18.46	g/m^3

TABLE 6. LIST OF STATIONS

	Station	Station Code	Period of Record	N
1.	Stuttgart	34041	1 Oct 46 - 31 Dec 70	212211
2.	Heidelberg	34046	18 Nov 46 - 31 Jul 47 1 Apr 54 - 31 Dec 70	149994
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9.	Fulda	35053	3 Sep 60 - 31 Dec 70	58841
10.	Berlin (Tempelhof)	35104	1 Apr 46 - 31 Dec 70	216786

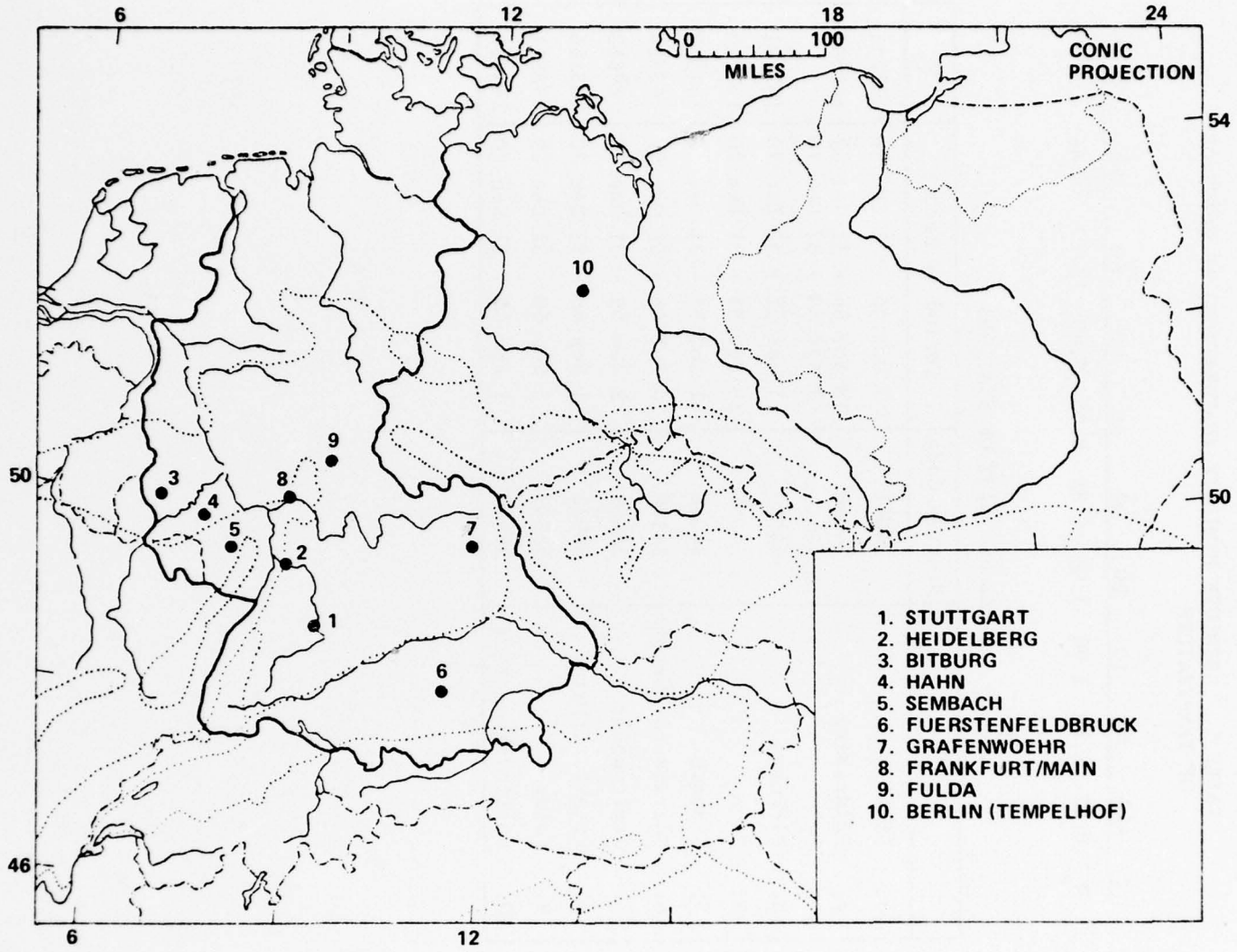

Figure 1. Location of stations.

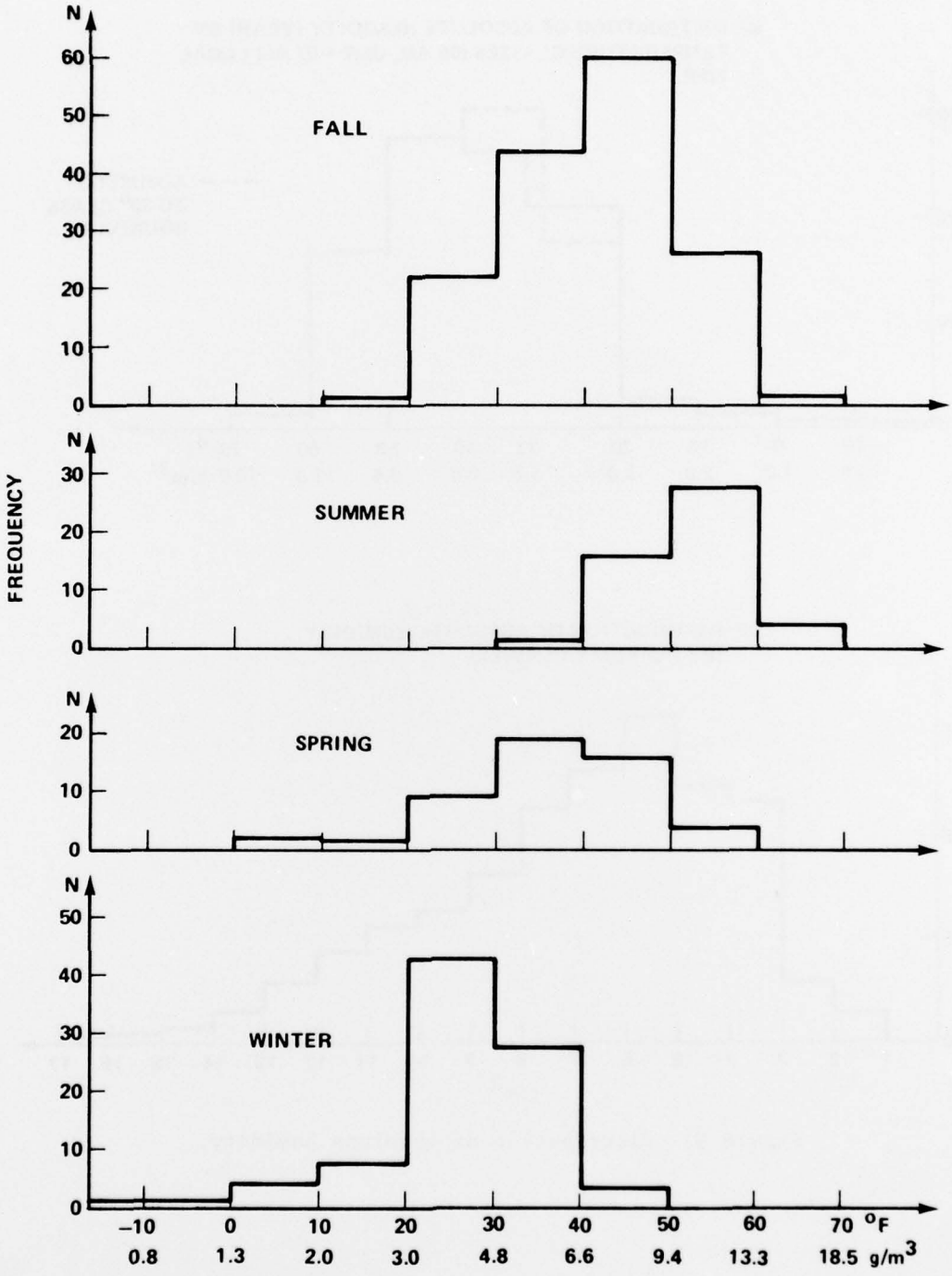

Figure 2. Seasonal distribution of temperature and absolute humidity in fog at 06 AM GMT = 07 AM local time.

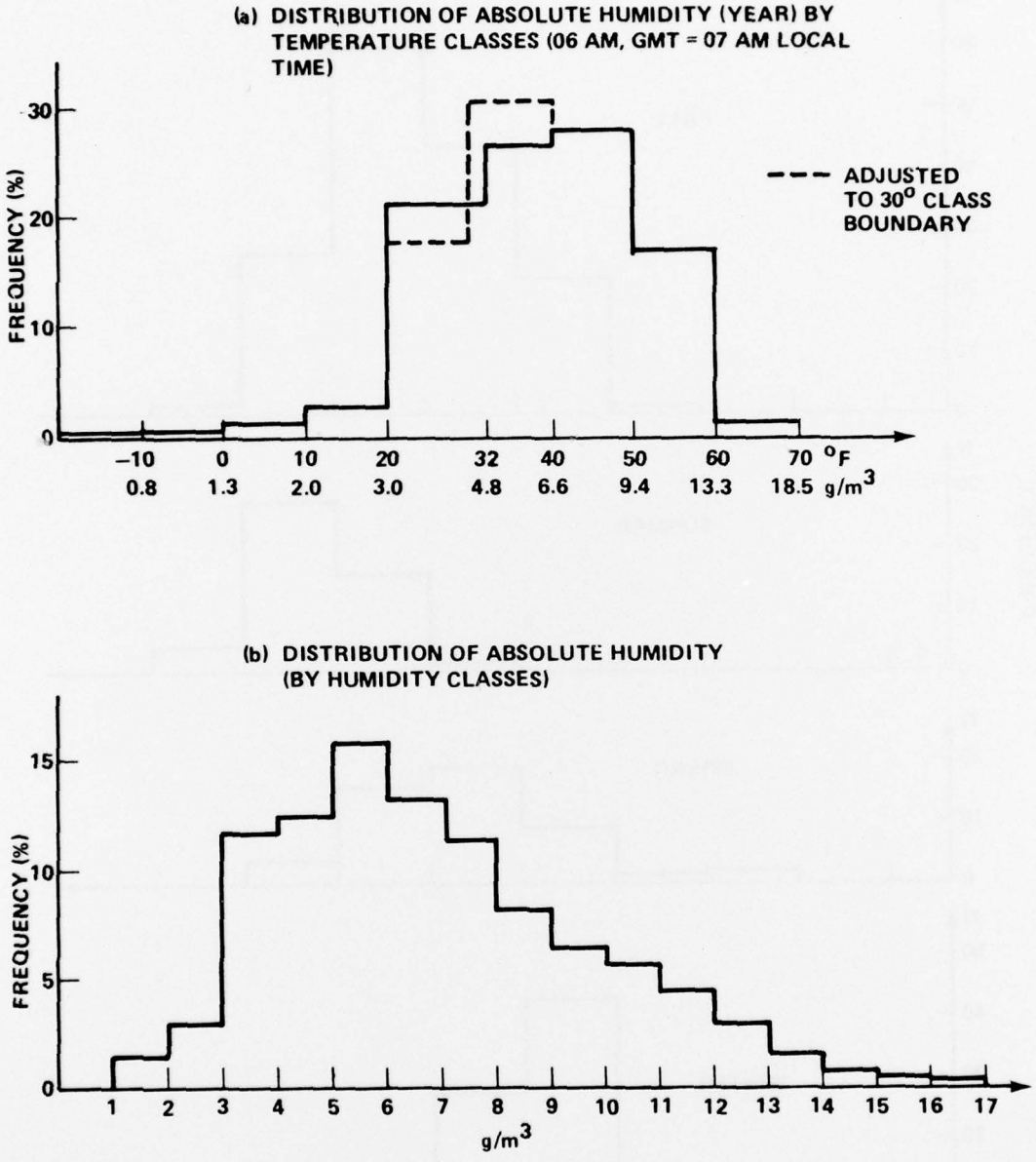

Figure 3. Distribution of absolute humidity.

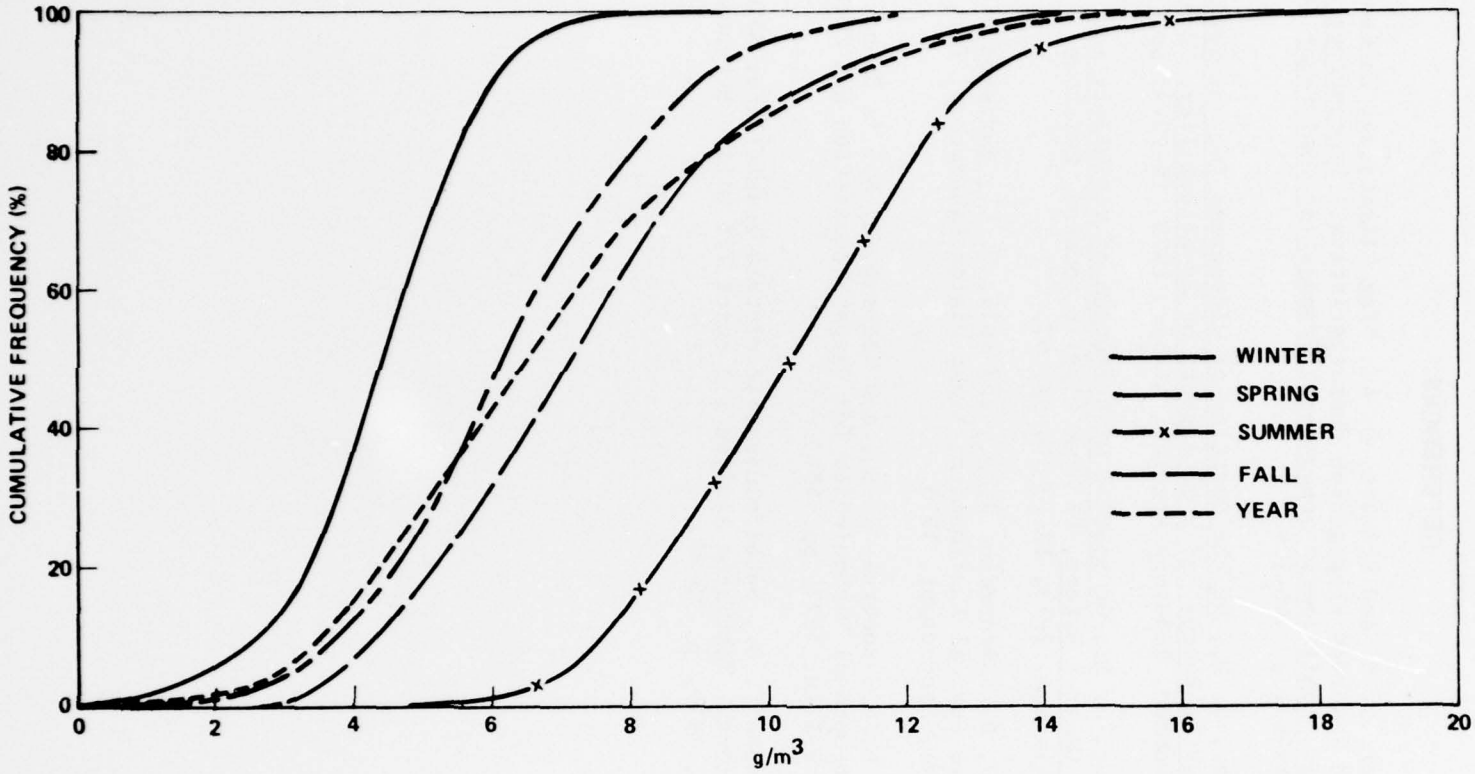

Figure 4. Cumulative frequency of absolute humidity during fog at 6^{h} AM GMT (= 07 AM local time).

REFERENCES

1. Essenwanger, O. M. and Stewart, D. A., "Fog Climatology in Central Europe and Inferred Propagation Characteristics," Proceedings of the Optical-Submillimeter Atmospheric Propagation Conference (6-9 December 1976), p. 165-179.

2. Essenwanger, O. M., On the Duration of Widespread Fog and Ceiling in Central Europe and Some Aspects of Predictability, US Army Missile Command, Redstone Arsenal, Alabama 1973, TR-73-9, pp. 57.

3. Essenwanger, O. M., On Spatial Distribution of Visibility and Clouds in Central Europe, US Army Missile Command, Redstone Arsenal, Alabama, 1973, TR-73-10, pp. 63.

4. Moulton, J. R., Bergemann, R. J., and Sola, M. C., European Winter Atmospheric Optical Environment, Night Vision Laboratory, Fort Belvoir, VA, Manuscript, 1976.

5. Biberman, L. M., Roberts, R. E., and Seekamp, L. N., "A Comparison of Electro-Optical Technologies for Target Acquisition and Guidance," IDA Paper P-1218, 1977, pp. 45.

6. Schulze-Neuhoff, H., *Nebelfeinanalyse mittels zusätzlicher* 420 Klimastationen, Taktische Analyse 1:2 statt 1:5 Mill. Meteorol. Rdsch. 29, 1976, p. 75-84.

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